Polarimetric Radar Remote Sensing of Ocean Surface Wind

Simon H. Yueh, William J. Wilson, and Steve Dinardo

Jet Propulsion Laboratory, MS 300-235
California Institute of Technology
4800 Oak Grove Drive, Pasadena, CA 91109, USA
Tel: 818.354.3012, Fax: 818.393.3077
E-mail: simon.yueh@jpl.nasa.gov

Abstract – **Experimental data are presented to support the development of a new concept for ocean wind velocity measurement (speed and direction) with the polarimetric microwave radar technology. This new concept has strong potential for improving the wind velocity measurement accuracy and for extending the useful swath width by up to 35 percent for follow-on spaceborne scatterometers to NASA SeaWinds missions. The key issue is whether there is a relationship between the polarization state of ocean backscatter and ocean wind velocity at NASA scatterometer frequencies (13 GHz). A set of aircraft flights indicated clear and repeatable wind direction signals in polarimetric Ku-band scatteroemter observations of sea surfaces at 10 m/s wind speed.** sp

I. INTRODUCTION

Global measurements of ocean surface winds are important for many meteorological and oceanographic studies. Many satellite scatterometers, including the NASA scatterometer (NSCAT) on board the Japanese Advanced Earth Observation Satellite (ADEOS-1) operating from September 1996 through June 1997, and the NASA SeaWinds scatterometer on QuikSCAT operating since June 1999, have been launched for the measurement of ocean surface wind fields. A root-mean-square accuracy of about 1 m/s wind speed has been reported.

The primary remaining deficiency of spacecraft scatterometers is their capability to make unambiguous detection of wind direction. The ability of scatterometers to make ocean wind velocity measurements is based on the sensitivity of radar backscatter to ocean surface wind speed and direction. To enable the retrieval of wind direction, the SeaWinds scatteroemters have to deploy a conical scanning antenna with two antenna beams. This scanning configuration allows radar measurements at one earth surface point from two (outer swath and near spacecraft nadir track) to four azimuth directions (Figure 1). The multiple azimuth radar measurements typically produce three to four possible wind direction solutions. To facilitate the selection among multiple solutions (ambiguity removal), the present scatterometer retrieval algorithms have to utilize the numerical weather analyses to initialize the wind fields for an iterative median filtering. However, the poor measurement geometry at near the s/c nadir track and outer swath, where the number of azimuth looks reduced to one or two, significantly limits the usefulness of retrieved wind vectors within these portions of swath. Techniques that can resolve this issue are important.

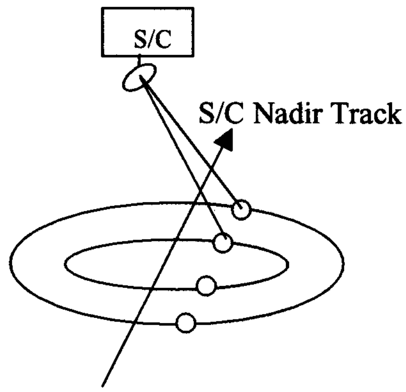

Figure 1. The measurement geometry of Seawinds scatteroemter on QuikSCAT.

A theoretical analysis using a two-scale scattering model [1] has suggested that the preferential directional orientation of wind-generated ocean waves has an influence on the polarization state of electromagnetic waves scattered by the ocean surfaces. It was predicted that the polarization state of active microwave radar backscatter from ocean waves has wind direction dependence, like the passive polarimetric microwave signatures [2,3].

The radar polarization signature of ocean surfaces can be described by a polarimetric scattering matrix:

$$S = \begin{bmatrix} S_{VV} & S_{VH} \\ S_{HV} & S_{HH} \end{bmatrix}$$

The first subscript of each scattering matrix element indicates the receiving polarization and the second subscript denotes the radar transmit polarization. “H” and “V” denote horizontal and vertical polarization, respectively. The square of each scattering matrix element represents the power of the radar echo for each polarization and is represented by the normalized radar cross section of sea surfaces, σ_0. The SeaWinds and NSCAT scatterometers were designed to acquire VV and HH σ_0s, which are symmetric with respect to the wind direction.

It was noted by the theoretical predictions that the correlation between the co- (S_{VV} and S_{HH}) and cross-polarized (S_{VH} and S_{HV}) radar backscatter from sea surfaces has an odd-symmetry with respect to the wind direction, unlike the symmetry property of σ_0s. If this is true, the correlation between co- and cross-polarized channels will provide additional information regarding the direction of sea surface wind, and may enable significant enhancement to the SeaWinds-like conical scanning scatterometers [4]. However, no radar observations were available to support this prediction.

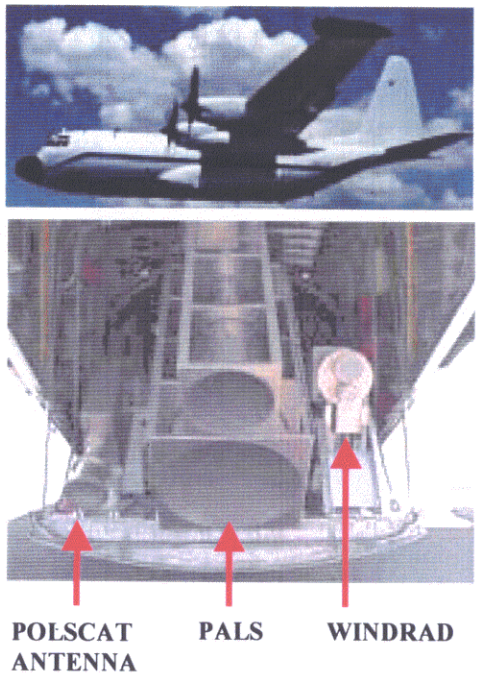

Figure 2. Ku-band Polarimetric Scatterometer deployed on the NCAR C-130 together with PALS and WINDRAD for flights over the MBARI buoys in August 2000.

II. POLARIMETRIC SCATTEROMETER

Our approach was to develop an airborne polarimetric scatterometer (POLSCAT) for proof-of-concept experiments. The POLSCAT operates at Ku-band (13.95 GHz), similar to the NASA SeaWinds and NSCAT scatterometer frequencies. POLSCAT was installed together with the JPL Passive/Active L-/S-band (PALS) microwave instrument designed for ocean salinity sensing on the National Center for Atmospheric Research (NCAR) C-130 aircraft. A set of flights was performed over the buoys deployed by the Monterey Bay Aquarium Research Institute (MBARI) off the California coast in August 2000. The other application of POLSCAT is to provide data to facilitate the analysis of PALS data for the remote sensing of ocean surface salinity. The C-130 flights were conducted over the buoys to investigate the wind direction sensitivity of polarimetric radar signals.

III. EXPERIMENTAL EVIDENCE

Fig. 3 illustrates the POLSCAT data acquired from ten different flight paths over the MBARI M2 buoy on August 16, 2000. The buoy wind was 10 m/s from the northwest. The data are plotted against the relative azimuth angle between the wind and antenna look directions with 0° indicating the upwind direction. The radar σ_0s, are plotted on the upper two panels. VV and HH σ_0s are symmetric with respect to the wind direction, consistent with the NSCAT and SeaWinds radar observations. VH and HV σ_0s of ocean surfaces, not yet reported in the literature, are also symmetric with respect to the wind direction. The other polarimetric radar measurements are the normalized correlation ($\rho_{\alpha\beta\gamma\delta}$) between $S_{\alpha\beta}$ and $S_{\gamma\delta}$ polarization. As shown, the correlation between VV and HH, ρ_{VVHH}, is symmetric with respect to the wind direction, while the correlation between co- and cross-polarized channels is anti-symmetric. This confirms the theoretical predictions that there are even and odd symmetry properties in the polarimetric radar signals of sea surfaces. Similar flight patterns conducted on August 17 yielded similar characteristics.

IV. SUMMARY

The aircraft POLSCAT data provide evidence supporting the use of polarimetric informatio for ocean wind measurements. The results indicate that there are orthogonal symmetry properties in the polarimetric radar signals of sea surfaces. The key remaining issues are that there are no data to allow

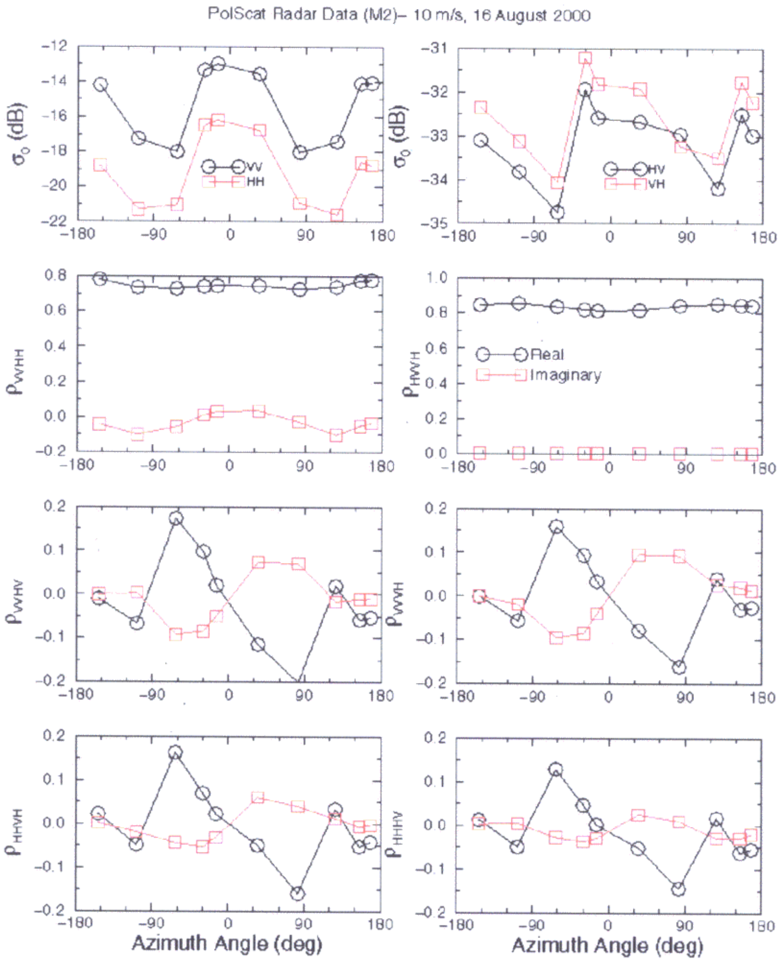

Figure 3. Polarimetric radar measurements of ocean surfaces versus ocean wind direction. The data were acquired by the JPL Polscat installed on NCAR C-130 with a set of flight lines over the MBARI buoy on August 16, 2000. Real and imaginary parts of $\rho_{\alpha\beta\gamma\delta}$ indicate in-phase and quad-phase components.

us to explore the signal sensitivity to wind speed and incidence angle.

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